

# Emission Reduction Methods, Theory, Practice and Consequences



Presentation at  
**Maritime Air Quality Technical Working Group**  
Meeting  
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by

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**Process Development**



L/74337-9.0/0502 (2430/NK)

## Emission Control

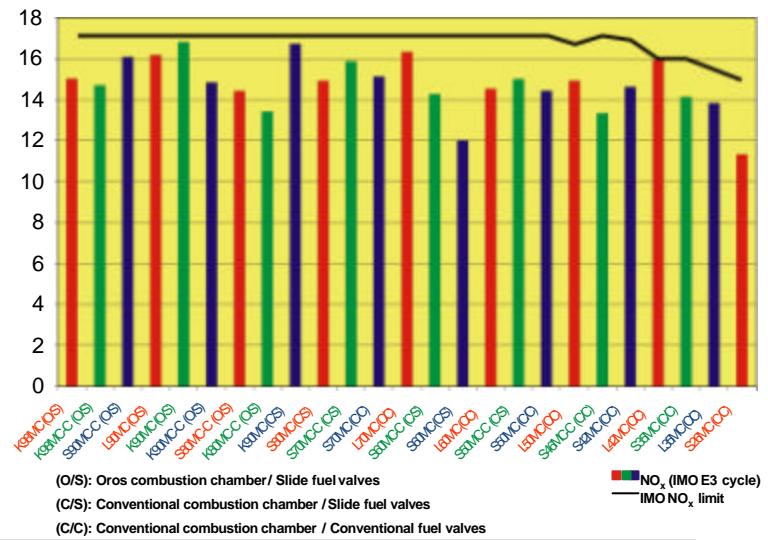


What are exhaust gas emissions from two-stroke diesel engines ?

- **NO<sub>x</sub> (Nitrogen Oxides NO, NO<sub>2</sub>)**
- **SO<sub>x</sub> (Sulphur Oxides)**
- **PM (Particulate matter)**
- **CO (Carbon MonoOxide)**
- **HC (Hydro Carbons)**
- **CO<sub>2</sub> (Carbon Dioxide)**

L/74217-0.0/0502 (2430/NK)

## All MAN B&W Diesel Engines Comply with IMO



## Increased Requirements for Emission Control



- Customer requirements
- Operational costs
- Legislation

## Emission Control



How can emissions be controlled ?

- Primary methods (Engine produces less NO<sub>x</sub>)

- 1) Engine adjustments
- 2) Engine process modifications

Water Injection; Water emulsified fuel

EGR (Exhaust Gas Recirculation)

HAM (Humid Air Motor, humidification of scavenge air)

- Secondary methods (NO<sub>x</sub> is removed after the engine)

SCR (Selective Catalytic Reduction NO<sub>x</sub>)

EPS (Electrostatic Precipitator, PM)

OC (Oxidation Catalyst, CO and HC)

L/74219-4.0.0502 (2430/NK)

## Emission Control



What is the cost for emission (NO<sub>x</sub>) control ?

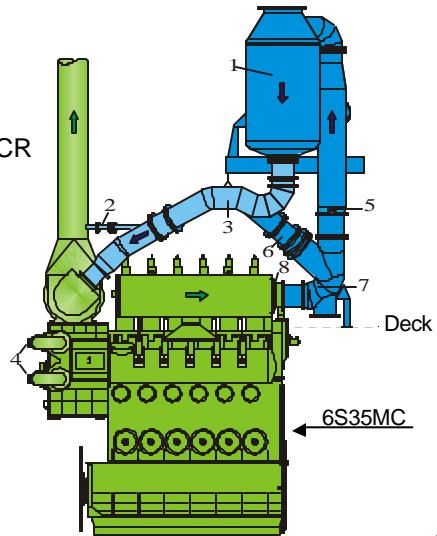
	Reduction capability in %	First cost In % of engine price	Running cost index
Primary methods			
Engine adjustments	0-30%	0%/Small	100
Engine process modifications	0-70%	3-20%	30-50
Secondary methods			
SCR (Sel. Cat. Reduction)	0-98%	50-70%	200-300

L/74220-4.0.0502 (2430/NK)

## SCR System



- 1 SCR reactor
- 2 Turbocharger bypass
- 3 Temperature sensor after SCR
- 4 Large motors for auxiliary blowers
- 5 Urea injector
- 6 SCR bypass
- 7 Temperature sensor before SCR
- 8 Additional flange in exhaust gas receiver



L/71835-9.0/0801 (2160/PZS)

## Conclusion on Emission Control



**Emission control is a requirement –  
and will be even more so in the future**

**Primary methods are significantly more  
cost-effective than secondary methods**

L/74340-2.0/0502 (2430/NK)

## NO<sub>x</sub> Reduction Capability

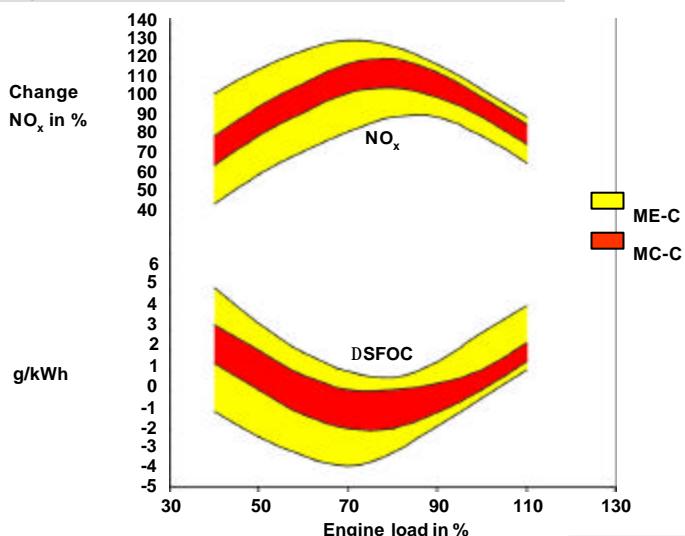


### Primary Methods

Engine adjustments for ME-C and MC-C engines

L/74333-1.00504 (2430/NK)

## Flexibility of the ME Concept

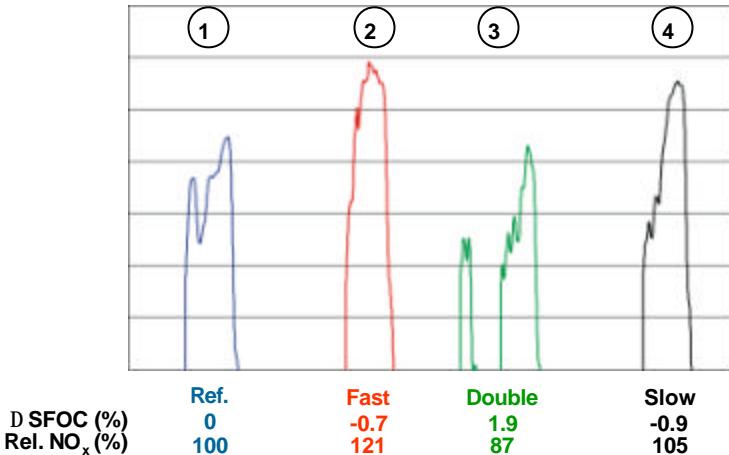


L/74336-7.00502 (2430/NK)

## Injection Profiles and Their Impact on SFOC and NO<sub>x</sub> Emissions



Fuel flow



L/74166-5.0/0402

(2430/NK)

## Emission Control



Conditions for NO<sub>x</sub> formation in cylinder.

- Combustion temperatures must be higher than 2100-2200 K.
- O<sub>2</sub> (O) and N<sub>2</sub> (N) must be present
- NO<sub>x</sub> concentration increases exponentially with temperature

L/74330-6.0/0502 (2430/NK)

## NO<sub>x</sub> Reduction Capability



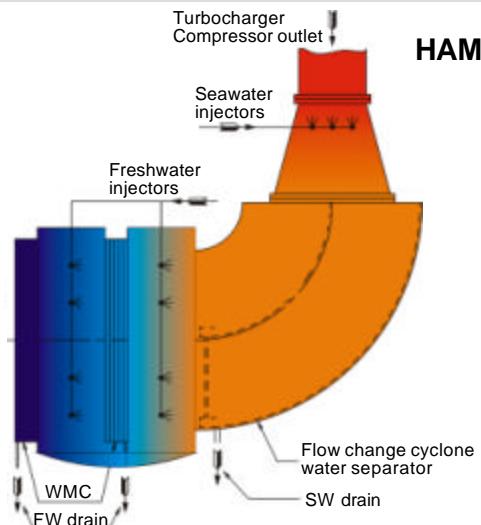
### Primary Methods

#### Engine Process Modifications

##### HAM Humid Air Motor, scavenge air humidification

L/74334-3.0/0502 (2430/NK)

## Principle Design of HAM system (Humid Air Motor)



#### HAM influence on NO<sub>x</sub> formation

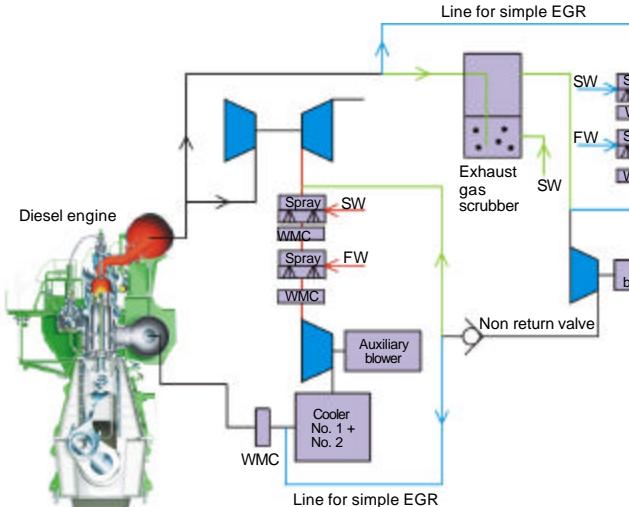
Humidification of scavenge air increases heat capacity and lower the O<sub>2</sub> content

High heat capacity and low O<sub>2</sub> in scavenge air give low combustion temperatures

Low combustion temperatures give low NO<sub>x</sub>

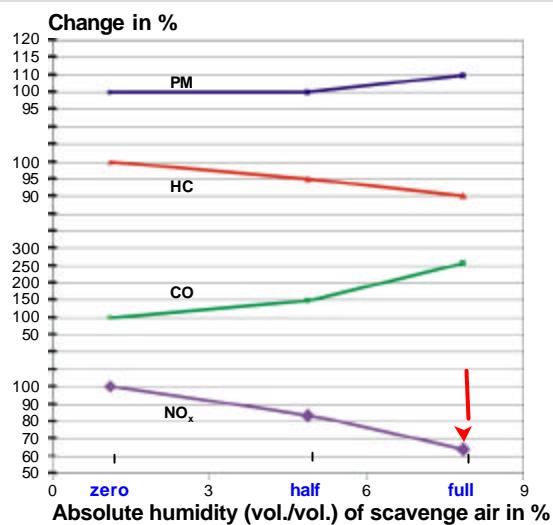
L/74222-8.0/0502 (2430/NK)

## Schematic Design of EGR and HAM Systems Application on 4T50ME-X



L/74160-4.00502 (2430/NK)

## Emission Parameters at 100% Load at zero, half and full HAM

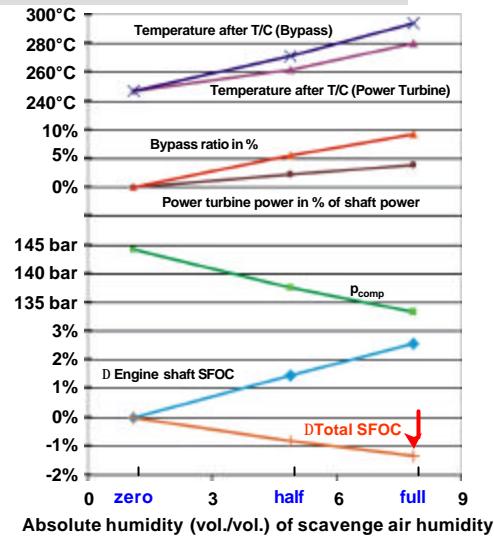


L/74170-0.00502 (2430/NK)

## Engine Performance at 100% Load at zero, half and full HAM



**Full HAM**  
correspond to 40%  
reduction of NO<sub>x</sub>



L/74169-0.00502 (2430/NK)

## Combustion Chamber Temperatures without HAM and with Full HAM



Running conditions/ components	Without HAM	With full HAM
Liner top °C	201	231
Piston top °C	435	453
Cylinder cover °C	295	312
Exhaust spindle seat °C	461	481
Exhaust spindle bottom °C	580	592

L/74329-6.00502 (2430/NK)

## NO<sub>x</sub> Reduction Capability



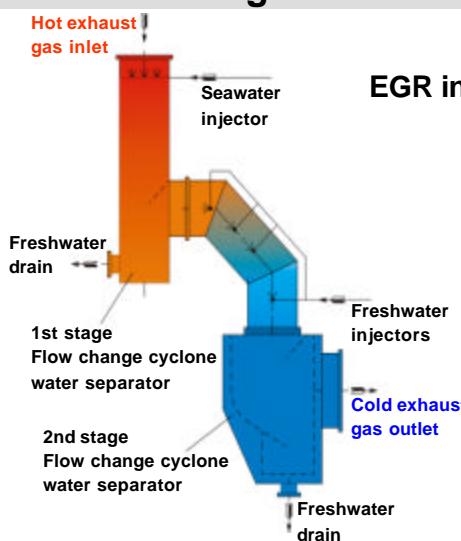
### Primary Methods

#### Engine Process Modifications

##### EGR Exhaust Gas Recirculation

L/74335-5.00502 (2430/NK)

## Schematic Design of EGR system



### EGR influence on NO<sub>x</sub> formation

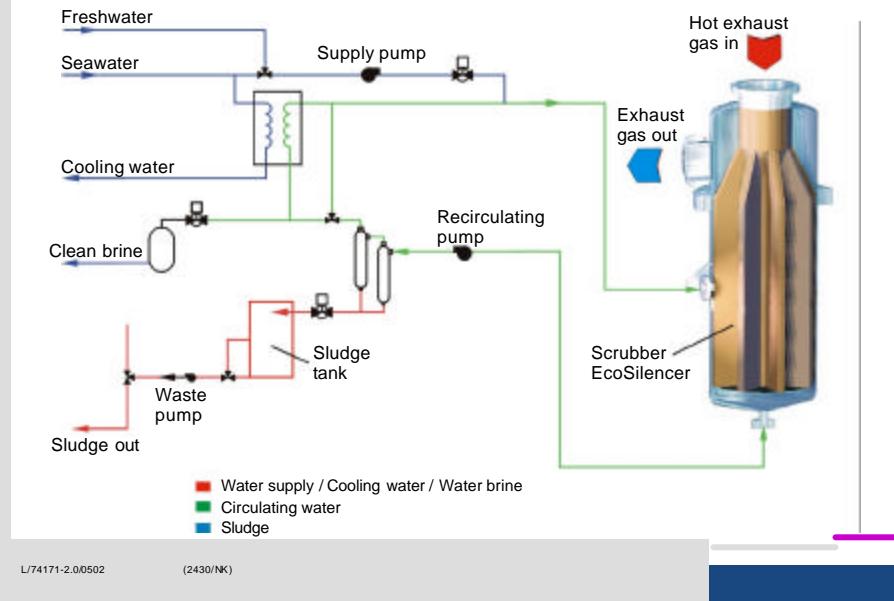
Re-circulation of exhaust gas lowers O<sub>2</sub> in scavenge air

Low O<sub>2</sub> in scavenge air gives low combustion temperatures

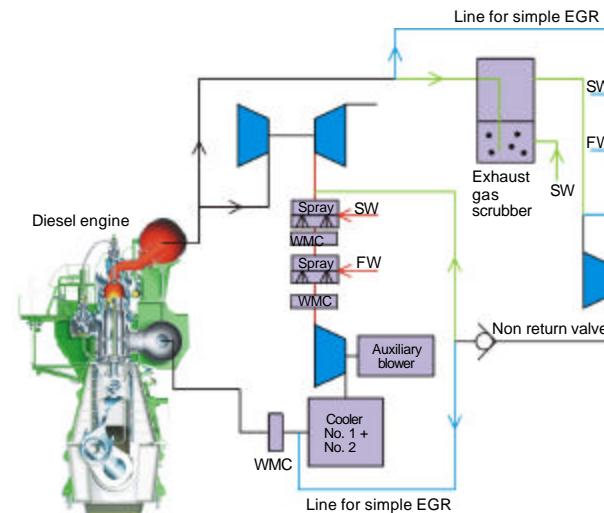
Low combustion temperatures give low NO<sub>x</sub>

L/74221-6.00502 (2430/NK)

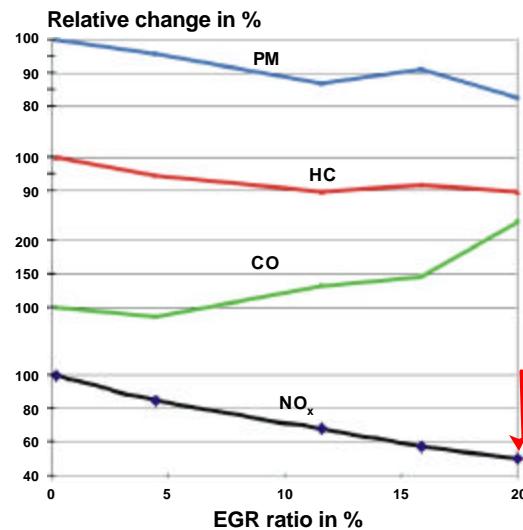
## "Bubble-bath" Scrubber (EcoSilencer) and Water Treatment Skid from DME



## Schematic Design of EGR and HAM Systems Application on 4T50ME-X

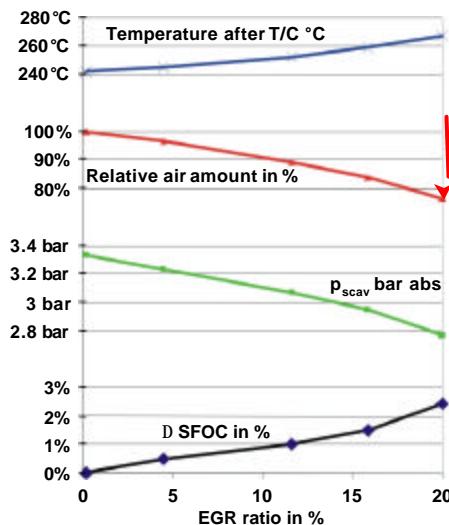


## Emission Parameters at 75% Load at Various EGR Ratios



L/74161-6.00502 (2430/NK)

## Engine Performance at 75% Load at Various EGR Ratios



L/74162-8.00502 (2430/NK)

## Combustion Chamber Temperatures without and with EGR



Running conditions/ components	Without EGR	With 15% EGR
Liner top °C	201	209
Piston top °C	401	412
Cylinder cover °C	253	257
Exhaust spindle seat °C	440	451
Exhaust spindle bottom °C	587	598

L/74328-4.0/0502 (2430/NK)

## PM on Filters before and after Scrubber

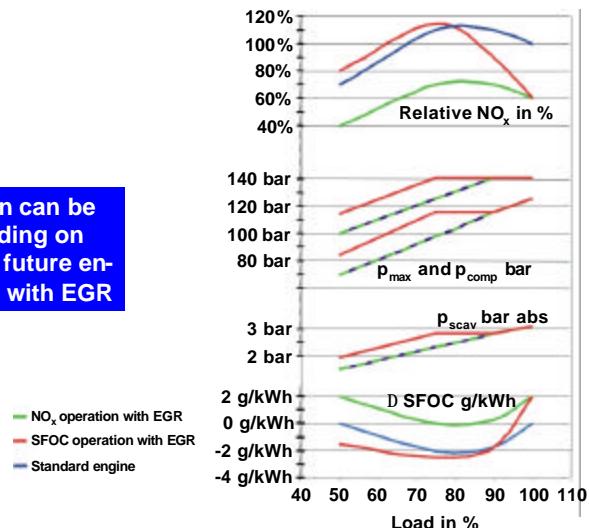


L/74164-1.0/0502 (2430/NK)

## Optimising SFOC/NO<sub>x</sub>

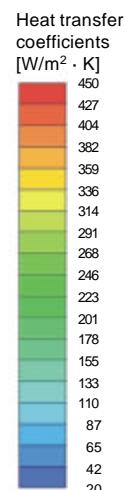
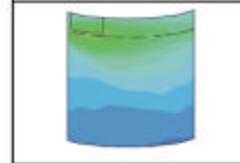
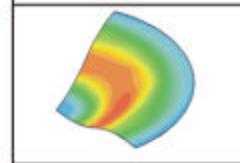
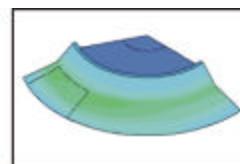
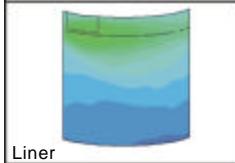
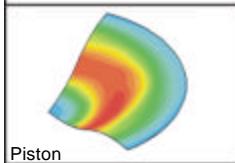
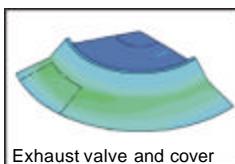


SFOC/NO<sub>x</sub> relation can be optimised depending on requirements for future engine applications with EGR



L/74165-3.00502 (2430/NK)

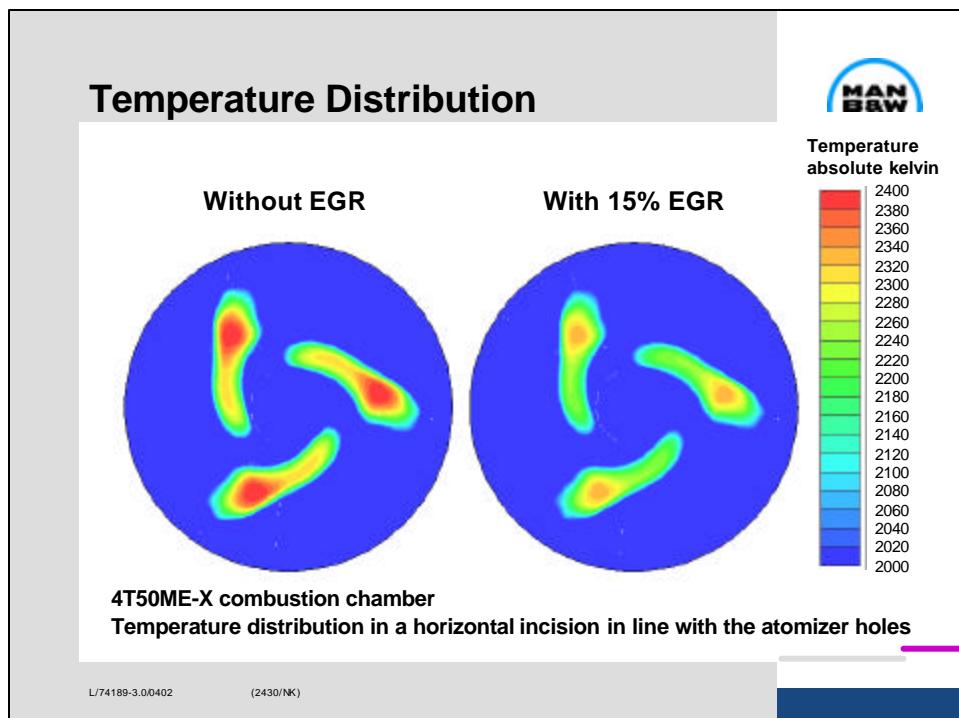
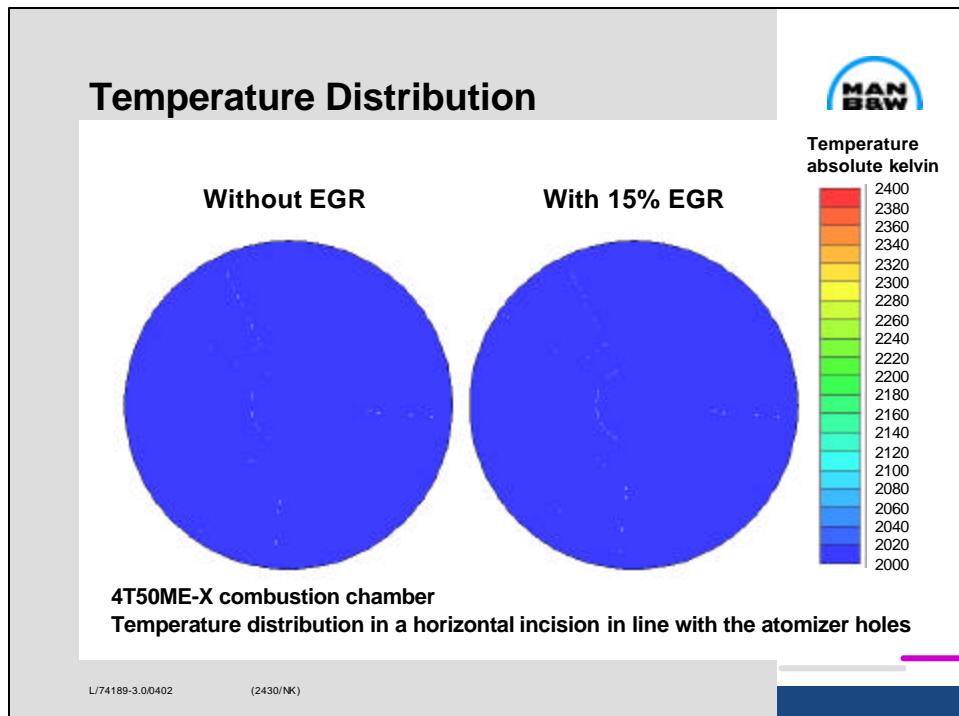
## Heat Load on Combustion Chamber Components without/with 15% EGR

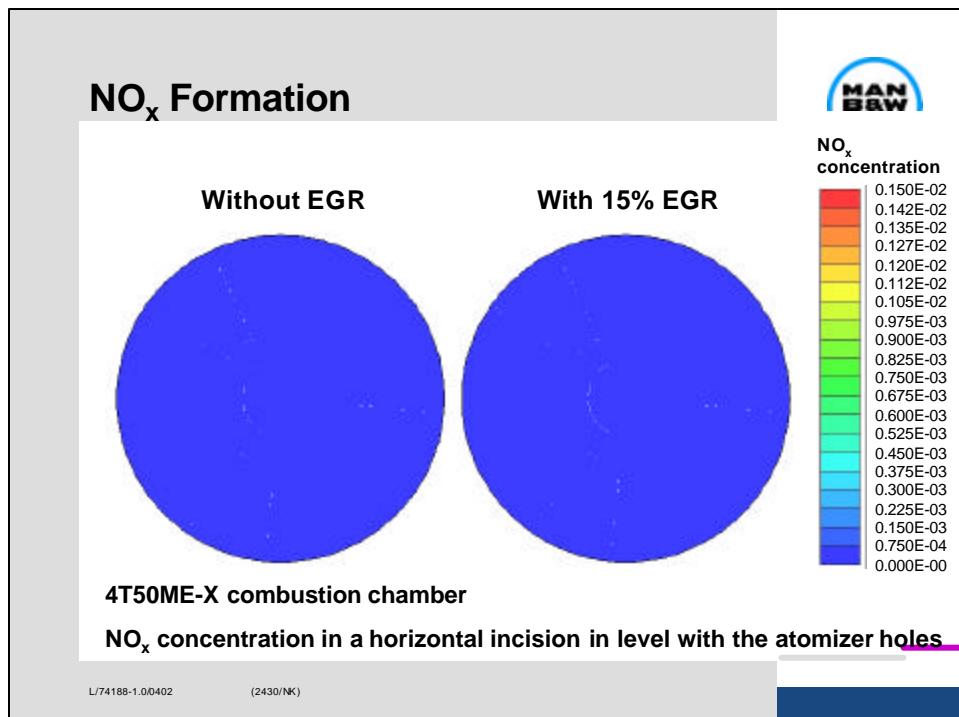
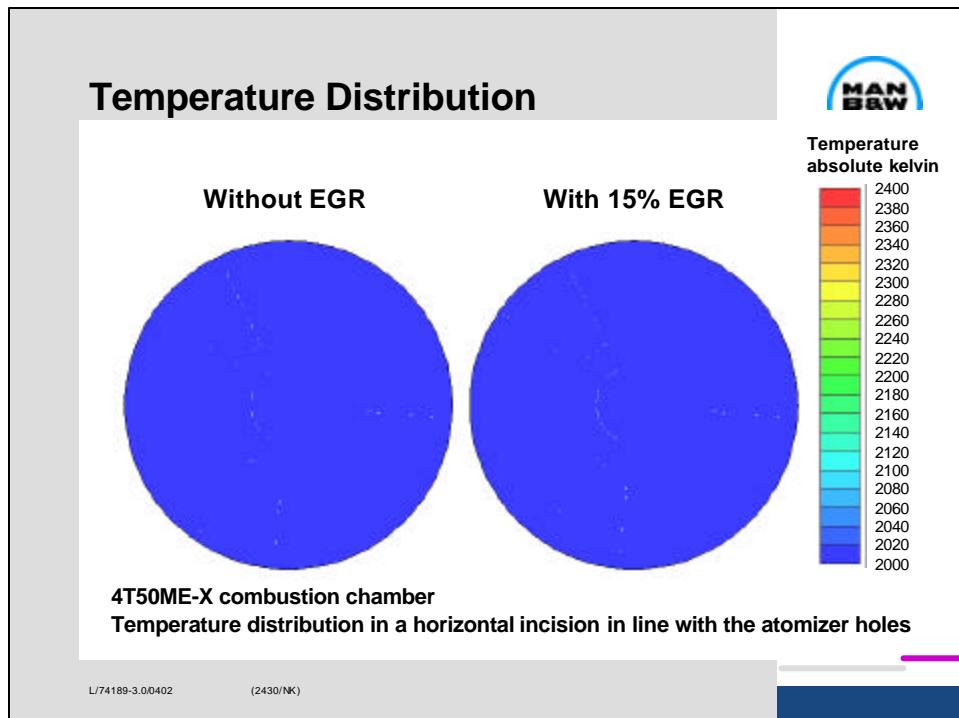


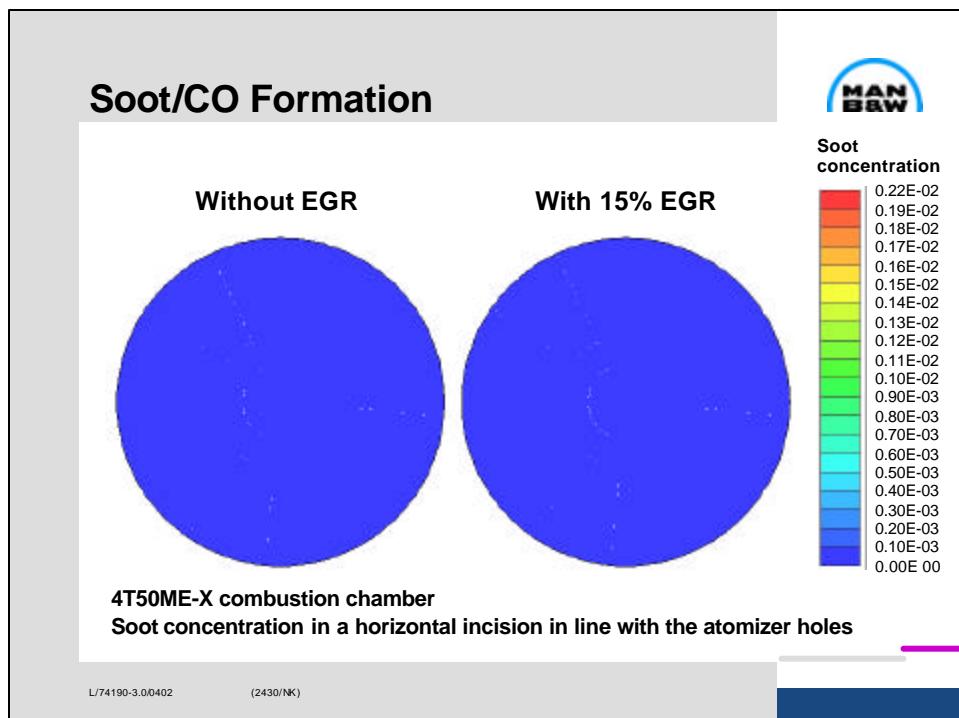
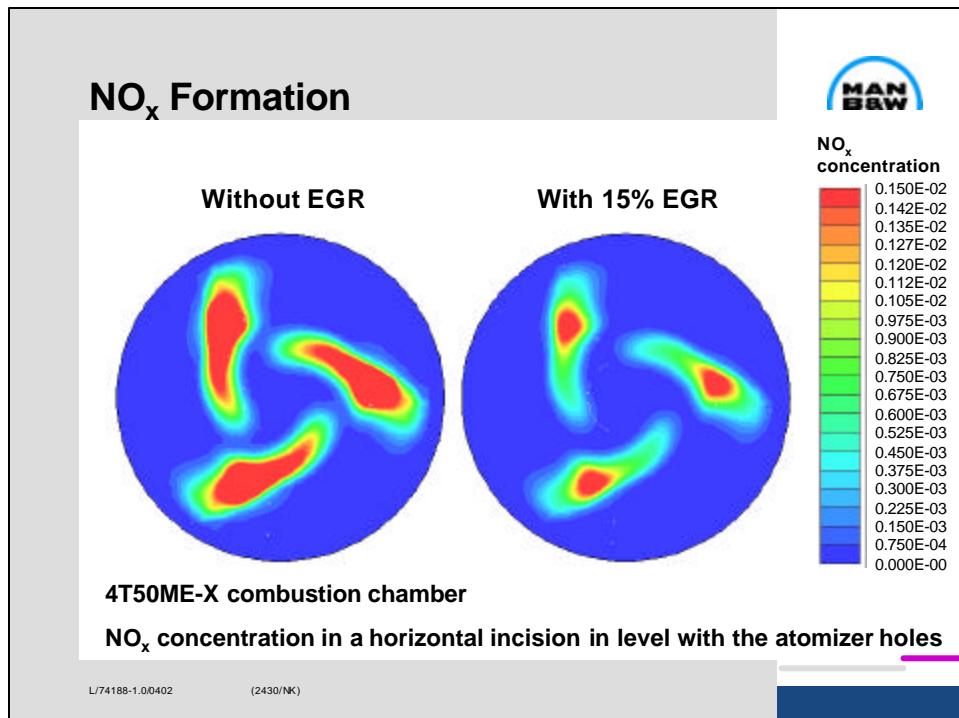
Without EGR

With 15% EGR

L/74159-4.00502 (2430/NK)



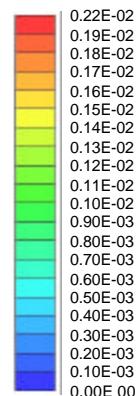




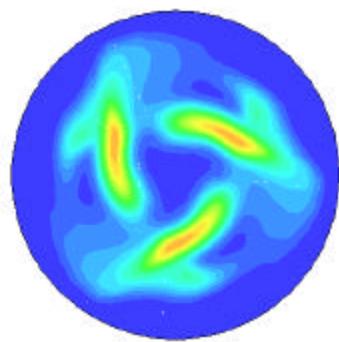
## Soot/CO Formation



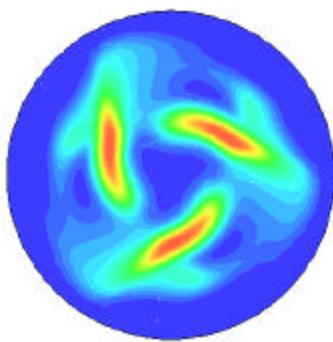
Soot  
concentration



Without EGR



With 15% EGR



4T50ME-X combustion chamber

Soot concentration in a horizontal incision in line with the atomizer holes

L/74190-3.00402

(2430/NK)

## CO<sub>2</sub> Emission



**Engine efficiency:** Limited scope  
for further CO<sub>2</sub> reduction

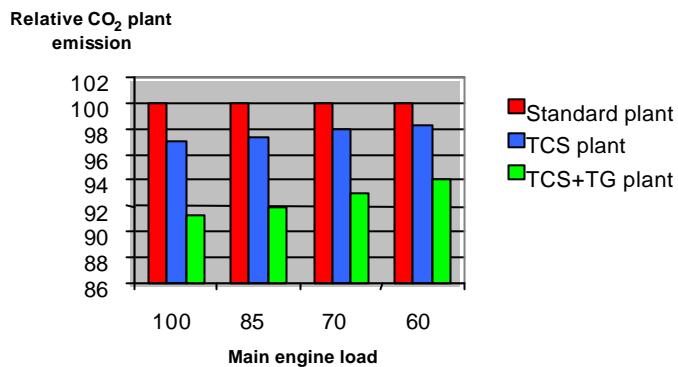
**Plant efficiency:** Good potential  
for CO<sub>2</sub> reduction

L/74338-0.00502 (2430/NK)

## Emission



**CO<sub>2</sub> emission from large container vessel with 12K98MC/MC-C and service electrical consumption of 7530 kW**



L/72825-7.0.0202

(3001/DT)

## Conclusion



**Emission control is/will be a key issue for engine applications**

**MAN B&W Diesel is, as illustrated, prepared for future requirements for emission control**

**MAN B&W Diesel will make development results available to the licensees**

L/74339-2.0.0502 (2430/NK)

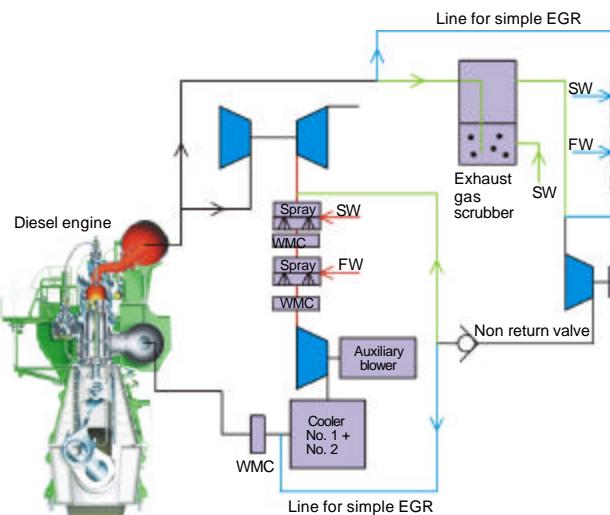
## Emission Reduction Methods, Theory, Practice and Consequences



# Thank you for your attention

L/74337-9.0/0502 (2430/NK)

## Schematic Design of EGR and HAM Systems Application on 4T50ME-X



L/74160-4.0/0502 (2430/NK)